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DISSERTATION

NOISE EXPOSURE AND RISK OF HEARING LOSS FOR AIR FORCE WELDERS

Submitted by

Jonathan W. Thomas

Department of Environmental and Radiological Health Sciences

In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Summer 2003

COLORADO STATE UNIVERSITY

June 5, 2003

WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY JONATHAN W. THOMAS ENTITLED NOISE EXPOSURE AND RISK OF HEARING LOSS FOR AIR FORCE WELDERS BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

NOISE EXPOSURE AND RISK OF HEARING LOSS FOR AIR FORCE WELDERS

Recent United States Air Force (USAF) studies hypothesized current measurement techniques are not adequately measuring welder noise exposures, and that welders are losing their hearing at a higher rate than expected based on attributable risk. The objectives of this study were to assess Electromagnetic Field (EMF) interference on welding noise exposure measurements and to assess noise measurement sampling rates and averaging times to determine potential differences in the amount of total energy characterized during routine exposure assessments.

Seven types of welding (shielded metal arc welding, gas metal arc welding, gas tungsten arc welding, flux core arc welding, oxy-fuel gas cutting, plasma arc cutting and air carbon arc gouging) were evaluated. Data were collected via a two-channel system using a microphone, pre-amplifier and front-end unit for each channel. The signals were saved to digital audiotape or a digital oscilloscope and then analyzed with a real time analyzer and the digital oscilloscope. One channel was used normally and the other was varied by three methods to evaluate the EMF interference effects. Sampling rates up to 25 MHz were used to collect exposure data.

Two of the three methods for evaluating EMF interference were effective. An inactivated calibrator provided 10 to 15 dBA of attenuation and was effective at attenuating noise

from 500 Hz to 16 kHz. For this objective, some EMF interference was present, but it did not have an appreciable effect on the measurements. For the second objective, increasing sampling rate did not increase the amount of energy measured and hence the dose did not increase.

The results of this study point to investigating additional avenues to explain the hearing loss of the welders. Other possible explanations include: ototoxins, non-occupational exposure, other noise sources, inadequate use of hearing protection or data anomalies in the audiograms.

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DISCLAIMER

The views expressed in this dissertation are those of the author, and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the U. S. Government.

CHAPTER 1

INTRODUCTION

A recent United States Air Force (USAF) study hypothesized that current measurement techniques are not adequately measuring welder noise exposures. Standard noise dosimeters are showing peak overloads indicating impulse levels exceeding 140 dBA (decibels A-weighted). These peaks are probably not being adequately integrated into the total noise exposure. Impulse measuring equipment indicated a high number of pulses per second, but found some radiofrequency interference with the measurements.[1] Another USAF report noted welders are losing their hearing at a higher rate than expected based on risk attributable given their noise exposures. The USAF average for 10 dB (decibel) losses/1000 audiograms is 30. Air Force welders are experiencing 68 (more than double) 10 dB losses/1000 audiograms.[2] A better method needs to be developed to assess the noise exposures and risk of hearing loss of Air Force Welders. This study assessed EMF interference on welder noise exposures and also assessed several sampling methods to evaluate welder noise exposures.

CHAPTER 2

LITERATURE REVIEW

2.0 Background on Welding and Related Hazards

There are numerous types of welding. The major categories and their percentage of total welding operations in the United States are listed in Table 1:[3]

Table 1: Types of Welding[3]

Types of Welding	Acronym	Other Names	% of Total
Shielded Metal Arc Welding	SMAW	Stick Rod Stick Coated Electrode	55
Gas Metal Arc Welding	GMAW	Short Arc MIG CO_2 Welding	15
Gas Tungsten Arc Welding	GTAW	Heli-Arc TIG	10
Oxy-fuel gas cutting or welding	OFC or OFW	Torch Welding/Cutting Gas Welding/Cutting	10
Plasma Arc Cutting	PAC	Plasma Cutting	<5
Air Carbon Arc Cutting	AAC	Air-arcing	<5

Welding hazards are frequently divided into toxic fumes and gases, ultraviolet light and noise. Toxic fumes and gases are considered the greatest hazard. Ultraviolet light is considered the next greatest and noise is the lowest hazard.[3] A rating scale of the risk of noise exposure for the major types of welding lists plasma arc cutting as the highest risk

and air carbon arc cutting as the next highest with SMAW, GMAW, GTAW and OFC listed as having a low hazard from noise.[4]

The National Institute of Occupational Safety and Health (NIOSH) recommends evaluating noise exposures for all welders. NIOSH lists plasma arc, metal spraying and arc air gouging processes as the most likely to have excessive noise exposures. Auditory impairment has been noted in welders from traumatic injury as well as noise exposure, when sparks and molten metal enter the ear causing traumatic injury. Noise induced hearing loss was noted in plasma arc and arc air gouging workers. A typical sound level meter is considered adequate for typical welding operations, but NIOSH has noted that these meters do not adequately measure impact noise. They also recommend controls (acoustic shields and total enclosures) for plasma arc welding and arc air gouging along with personal hearing protection if engineering controls cannot keep exposures below 85 dBA as an 8-hr Time Weighted Average (TWA).[5]

2.1 Background on Noise Criteria

The current Occupational Safety and Health Administration (OSHA) noise standard advises impulsive and impact noise exposure should not exceed 140 dB.[6] The current International Organization for Standardization (ISO) standard recommends combining continuous and impulsive noise via integration.[7] NIOSH recommends following the international approach, but presents arguments for and against this assessment method. Two different approaches have been suggested. One supporting the Equal Energy Hypothesis (EEH) and one arguing against it.[8] The EEH states that all types of noise are

equally damaging in relation to the amount of energy in the noise. In other words, the energy from continuous and impulse noise is equally damaging and is additive. Several studies provide evidence that impulse noise does not support the EEH.[9,10] In general, these studies not supporting the EEH state that continuous and impulsive noise have synergistic effects when combined. Animal studies indicate that the effects of exposure at high noise levels are synergistic, but at levels experienced in the workplace (below 140 dBA) the effects are additive. One method for addressing synergistic effects is to add a correction factor to noise exposure levels when continuous and impulsive noise exposure occurs concomitantly. NIOSH suggests that regardless of the additive or synergistic effects of exposure, impulse noise must be considered when combined with continuous noise sources.[8]

Previously, ACGIH had recommended assessing impulse/impact noise separately from continuous noise. Impulses/Impacts were defined as discrete noise of short duration (less than 500 milliseconds) where the sound pressure level rises and decays rapidly. The guideline was based on limiting the number of impacts at certain levels per day (example 100 impacts of 140 dB per day). Because of recent research showing the potential synergistic effects of continuous and impulsive noise, they now recommend integrating both types of noise to measure the total energy of exposure. ACGIH also notes that current instrumentation already integrates impulse/impact noise with the continuous noise, but they do not discuss the response limitations of current instrumentation to measure impulse/impact noise. They also note that the synergistic effects seem to disappear at exposure levels near their Threshold Limit Value (TLV) of 85 dBA. The

ACGIH TLV is not applicable to peak exposures above 140 dBC (decibels C-Weighted).[11]

Certain chemical exposures may cause hearing loss. Such exposures may influence hearing with or without noise exposure, and the threshold for these chemicals to cause hearing loss is not known. ACGIH recommends annual audiograms for personnel exposed to levels equal to or greater than 20% of the TLV for known ototoxins. In addition, employers/employees are cautioned to be alert for synergistic effects between noise and ototoxins. ACGIH has listed n-butanol, lead, manganese and toluene as having ototoxicity.[11] This advisory is relevant to welding since lead and manganese are known hazards of welding operations.[3]

The USAF does not follow the requirements of the Occupational Safety and Health Administration (OSHA) noise standard. To describe the USAF Hearing Conservation Program (HCP) criteria, a few definitions are needed. First, the criterion level is the 8-hour equivalent that results in a 100% noise dose measurement. Next, exchange rate defines the increase or decrease in sound level for a corresponding halving or doubling of exposure time. The exchange rate is also called the trading ratio or doubling rate. Finally, $L_{eq,T}$ is the equivalent continuous A frequency-weighted sound level over a time T. If T is 8 hours, $L_{eq,8}$ becomes the time-weighted average, or TWA.[12]

The USAF program presently uses a criterion level of 85 dBA and a 3 dB exchange rate. Individuals are allowed noise exposures unprotected at sound pressure levels less than 85

dBA. USAF members are placed on the HCP if the TWA equals or exceeds 85 dBA and hearing protection is required. Previously, the USAF used a criterion level of 84 dBA and a 4 dB exchange rate. The use of the current criterion level and exchange rate started in December 1993.[12]

2.2 Background on Impulsive Noise

High peak sound pressure levels (SPL) noise transients are frequently described as impact or impulse noise. These terms are often used interchangeably but they have different definitions. Impulse noise is a noise transient resulting from a sudden release of energy into the atmosphere. Typical sources are gunfire and air blast from circuit breakers. Impact noise is a noise transient resulting from the impact between two objects. Typical sources are a hammer striking a metal plate or a punch press. Traditionally 140 dB has been used a dividing line between impulse and impact noise. Most industrial impact sources are less than 140 dB and many impulse sources far exceed 140 dB. Also, below 140 dB there is no practical difference physically between impact and impulse noise sources, because the shock wave indicative of impulses starts to breakdown.[13]

In a study evaluating the temporal pattern of traumatic exposure to impulse noise, the authors concluded the EEH has boundary conditions. At impulses of 135 dB the EEH worked, but at peaks of 150 dB conditions were found to be more hazardous than would be predicted using the EEH.[14] Since welding impulses appear to be less than 140 dB, the EEH should be applicable from a temporal pattern standpoint.

In addition to noise exposure, several physical and chemical factors have an effect on hearing loss. The chemical factors are medication, smoking, toxic gases and ototoxic substances. These factors interact systemically via the nervous system or blood circulation. Thus the effects are on the body's metabolic processes including the inner ear. The types of physical energy are acoustical energy, radiation energy and heat energy. The acoustical energy is in the form of whole-body or hand-arm vibration. The radiation energy may be from a wide spectrum of electromagnetic frequencies from ionizing radiation to the radiofrequencies; ionizing radiation and microwaves are of greatest concern in occupational settings. The heat energy is normally in the form of physiologic heat production resulting from physical exercise or muscular work.[15]

A NIOSH study suggests that impulse noise dosimetry has two related problems. First, impulsive exposure has uncertainty in the dose/response relationship. Second, there is no acceptable instrumentation to evaluate impulsive noise. Authors of this study suggest new dosimeter design be applied to solve the instrumentation problem so that a scientifically sound dose/response relationship can be developed. There are some possibly useful interim solutions using currently available equipment, which will be discussed in more detail in the methods section of this paper. Such approaches may make impulse noise measurements much more accurate for noise dosimeters. [16]

Peak pressure and duration are key parameters used to assess impulse noise hazard and are used in most international noise exposure limits. A rough relationship has been found between these parameters and hearing loss, but this relationship breaks down when

comparing different types of impulses. Differing frequency spectrums between impulses of the same peak pressure have been found to cause differing amounts of hearing loss. Weighted (by frequency) energy is an alternate method of measuring impulse intensity that is appealing for a several reasons. Weighted energy does not depend on details of the pressure-time history (peak pressure and duration); it is easier to combine with current continuous noise standards; and standard hearing protection attenuation criteria could be used to estimate the hazard if weighted energy was used. These attributes lead to the conclusion that by controlling for spectral effects (since the human ear is more susceptible at certain frequencies) weighted energy is a better indicator of hearing hazard than peak pressure.[17]

Using energy as an indicator of auditory hazard ties into the EEH. There are three separate hypotheses in applying the EEH concept to impulse noise. First, energy can be used to assess the hazard from a single or multiple impulses with different characteristics. Second, the EEH implies a specific trading relation between the number of impulses and intensity (e.g. 3-dB reduction of intensity for each doubling in the number of impulses). Last, the EEH implies that temporal spacing should not affect the hazard from impulses. Each of these hypotheses may or may not be true, but they can each be tested.[17]

2.3 Previous Studies on Welding and Impulse Noise

A study has suggested using the difference between the A-Weighted peak level (L_{AP}) and the A-Weighted root-mean-square (RMS) level (L_{AS}) as a measure of impulse hazard. This difference is an A-Weighted crest factor and is dependent on the time duration of the

signal. The authors suggest L_{AP}-L_{AS} is a viable indicator of impulsiveness over a 10-s interval. This definition was used to develop a statistical procedure to assess the impulsiveness of varying industrial sources. The authors measured an impulse percentage F15, which is the percentage of time the difference is greater than 15 dB and is derived from the cumulative distribution function of the differences. This technique was used to look at a number of noise sources and occupations. MIG (GMAW) welding was found to be the most impulsive noise source (other sources included rod welding, grinding, chiseling and gouging). The transient analysis of MIG (GMAW) welding found peak levels of 116 dB (100-microsecond duration) occurring randomly. It was also found that welders have the most impulsive exposures compared to grinders, platers and lumberjacks.[18]

Air Force consultants performed a noise evaluation of several welding operations. They looked at SMAW, GMAW, GTAW and AAC. They found workers were not adequately protected by current Air Force standards. No peaks were measured above 140 dB, implying an unlimited number of peaks were allowed without requiring hearing protection. For GMAW, they found RMS levels to be near 98 dB for the entire duration of a sample because of the high number of peaks per sample. In general, they found the number of pulses per second to range from a few to hundreds. They concluded single hearing protection should be worn during all welding operations and further study was needed to assess the impulse noise hazards of welding.[1]

2.4 Measurement Methods for Impulse Noise

AF consultants used a digital storage oscilloscope with a Bruel and Kjaer (B&K) 4136 Microphone. They used a sampling rate of 1 microsecond per point in an attempt to get adequate measurement duration to capture peaks and adequate resolution for accurate measurements. They noted several problems with their approach. First, high pulse density would normally be defined as continuous noise rather than impulse noise. Second, the sampling rate was not fast enough to fully capture GTAW welding peaks.[1]

A study by Stark etal on measurement of impulse noise used a conventional measurement system with B&K components (4136 microphone, 4426 preamp, 2210 amplifier and 7003 analog tape recorder). A hold and reset circuit was used so peaks of moderately spaced impulses could be detected. They found welder noise exposures to be more impulsive than platers or grinders.[18]

Erdreich looked into the problems and possible solutions for conducting impulse noise dosimetry. The Slow response network of a dosimeter is a major limitation. The inability of the network to respond to impulses of short duration may cause an under or over estimation of the dose. Microphones were evaluated based on their frequency response to impulses. ½-inch microphones were listed as a minimum requirement with ¼ -inch considered superior. The typical impact energy was found to be within the pass band of the A-Weighting Network, therefore A-weighting is not a limiting factor of dosimeter impact measurement. A mathematical evaluation of sampling rate and averaging time found that by reducing the averaging time to zero (i.e. equal to the

sampling rate), very little error was introduced using a 5 dB exchange rate, and no error was introduced when using a 3 dB exchange rate. The authors recommended reducing the time constant to less than 30 milliseconds, as this will have almost no effect on continuous noise measurements. This change will make impulse noise measurements much more accurate for noise dosimeters.[16]

Additional studies also looked at the various methods to evaluate impulse noise. Pekkarinen used a ½ " microphone and analog tape recorder and then sampled the signal at speed of 400 Hz. They also used a peak detector with a hold circuit. The author found the sampling speed was adequate to measure real time peak levels and RMS levels. Ten minute sampling periods were used.[19] This result indicates using a digital oscilloscope sampling at intermediate speeds would have exceed their sampling rates and still have adequate measurement time.

Another study by Erdreich used a digital oscilloscope for pulse measurements and an analog tape recorder for continuous measurements. He used the B&K 4136 microphone because of its excellent pulse response. This study found that technological developments in instrumentation provide for much better evaluation of impulse noise since researchers do not need to use A-weighted slow response instruments.[20]

A study by Hamernick etal recommends a minimum sampling frequency of 160K samples/second for digital systems. Aliasing problems from analog-to-digital (A/D) conversion can be avoided via the use of a low-pass filter prior to digitizing. The cutoff

frequency for the low pass filter should be set to about 1/3 the sampling frequency. It also recommended that the A/D converter have a resolution of at least 12 bits. This approach limits the amount of distortion in measuring impulse noise.[13]

2.5 Background on Welding Noise Exposure Surveys

Several noise exposure assessments for welders are available. To make these assessments comparable, all the study results were normalized to an average daily (8-hour) exposure or Time Weighted Average (TWA). Measurements were assumed to be TWAs measured in dBA collected over 8 hours by a standard noise dosimeter unless otherwise stated.

As part of a larger study of worker noise exposures, welders at an Air Force Base (AFB) had their noise exposure measured with six workers showing a TWA of 91 dBA. These doses where calculated with the old AF exposure standard of 84 dBA with a 4 dB exchange rate. The welding shop was near a flightline, but the survey determined that flightline noise was not the primary source of exposure. Area noise dosimetry in the building was less than 75 dBA during all work shifts evaluated.[21]

A Finnish study examined 57 noise-dose measurements in welding shops. Overall the TWA was 92 dBA. They also conducted octave band analysis of the welding noise sources and found that high frequencies dominate welding noise. The highest noise levels were usually in the frequency range of 4 to 8 kHz. They also developed a metric to look at the impulsiveness of welding noise and found MIG welding to be very impulsive.

Arc welding has some impulsive nature and AAG was not very impulsive. The TWAs are summarized in table 2.[22]

Table 2: Welding Noise Exposure Levels from Finnish Study

Operation	Median Level (dBA)	Number of Samples
AAC	114	18
Grinding	103	33
PAC	101	6
GMAW	89	30
OFC/OFW	86	6
SMAW	78	19
GTAW	62	8

A German review of noise problems while welding examined the TWAs of several welding processes. It was found that arc welding showed exposure levels of 85 dBA (94 dBA if slag chipping was included); GMAW (CO_2) was 91 to 95 dBA; GMAW (MIG) was 95-102 dBA; GTAW was 65-74 dBA; PAC was 100 to 110 dBA; and AAC was over 103 dBA.[23]

Another German study looked at how noise and fume affect welders. This study looked at SMAW, GMAW (MIG and CO_2), and GTAW welding. They found the sound levels increased for all cases as the amount of energy used to weld increased for each process. They found SMAW to range from 70 to 80 dBA (ignoring incidental work); GMAW

(CO_2) ranged from 80 to 87 dBA; GTAW ranged from 79 to 83 dBA; and GMAW (MIG) ranged from 87 to 94 dBA.[24]

The American Welding Society (AWS) studied arc welding and cutting noise using a standard protocol they had developed. This protocol was designed to allow repeatability of measurements. They used standard sound level meters setup in a specialized room for measurements. The room had the walls covered by absorptive material with a reflective floor and a high ceiling. They recommend at least 8 feet of clear space on all sides of a welder. They also placed the welding machine outside the welding booth so it wouldn't contribute to the noise levels. A summary of their measured levels for each operation are listed in table 3.[25] This procedure provides for good repeatability but does not account for the welder's typical exposure since reverberation is limited and the welding machine is not in the test environment.

Table 3: Welding Noise Exposure Levels from AWS Study

Operation	Decibel Range (dBA)
GTAW	50-55
GMAW	75-80
FCAW	80-85
SMAW	70-80
AAC	100-110

Rodgers conducted a study of hearing conservation in fabrication shops. The author conducted noise measurements as part of the justification for HCPs in fabrication shops. Daily personal noise exposures were evaluated for three groups of shop workers (welders, platers and grinders). The welders had an average TWA of 93 dBA (14 measurements). Platers and grinders had TWAs of 94 and 103 dBA. The noise measurements were not meant to be comprehensive evaluations, but were to point out the need to take action to protect workers.[26]

Rezmer et al conducted a noise assessment of fabrication shops in Colorado. Twenty shops and 137 workers were evaluated with full shift noise dosimetry. The authors found fabrication workers are overexposed to noise. Workers were divided into 11 job categories. Grinders, welders and fitters were found to have the greatest risk of exposure. The eighteen welders evaluated had an average TWA of 89 dBA.[27]

A review of welding noise as a health hazard in Japan provided exposure levels for various welding operations. The table 4 includes the range of levels encountered.[28]

Table 4: Welding Noise Exposure Levels from Japanese Study

Operation	Decibel Range (dB)
SMAW	76-87
GMAW (CO_2)	86-96
GMAW (MIG)	94-105
GTAW	79-115
PAC	100-123

Erlandsson et al conducted a study to look at the difference in protection efficiency between plugs and muffs. Hearing protectors were evaluated by looking at workers in an assembly shop and boiler shop. Welders in both shops had their daily noise exposure measured over 6 days. The assembly shop workers had a daily exposure of 91-95 dBA (11 welders). The boiler shop workers had a daily exposure of 94-96 dBA (8 welders).[29]

Fannick and Corn's survey of the industrial hygiene hazards of plasma torches included octave band and overall decibel measurements. Levels while cutting steel ranged from 104 to 113 dB with most of the energy at 2000 or 4000 Hz.[30]

In summary, these evaluations of welder's noise exposures point out that exposure levels can routinely exceed 90 dBA and hearing protection while welding in these environments is definitely needed.

2.6 Background on Welding Electromagnetic Field Exposures (EMF)

Concerns have been raised about the potential for EMF interference with the measurements systems for evaluating welder noise exposures. To look at this potential interaction several studies were reviewed which evaluated EMF exposures of welders.

Prasad and Vyas studied the effects of EMF on workers and found a level of over 250 Tesla on over 50% of iron welding machines.[31] Dasdag et al also looked at the effects of Extremely Low Frequency – EMF on welders. This survey did not find any effects but did note levels of several hundred microTesla near the bodies of welders.[32] These studies quantify the potential levels of EMF near welders and indicate the need to evaluate their effect on measurements.

2.7 Background on Welding Hearing Loss and Protection

Since AF welders are experiencing a high incidence of hearing loss, several studies were reviewed which look at hearing loss in industrial welders. A review of construction noise exposures included a summary of eight construction job specialties showing incidence of hearing loss. Welders, with a 29% incidence, had the second highest rate of the group. It also listed the average use of hearing protective devices at 15% for all construction workers.[33] A Finnish Study noted that 63% of the reported occupational diseases in welding shops were from occupational hearing loss.[28] These studies along with the noise exposure levels of previous studies indicate welders do have a strong potential for hearing loss.

CHAPTER 3

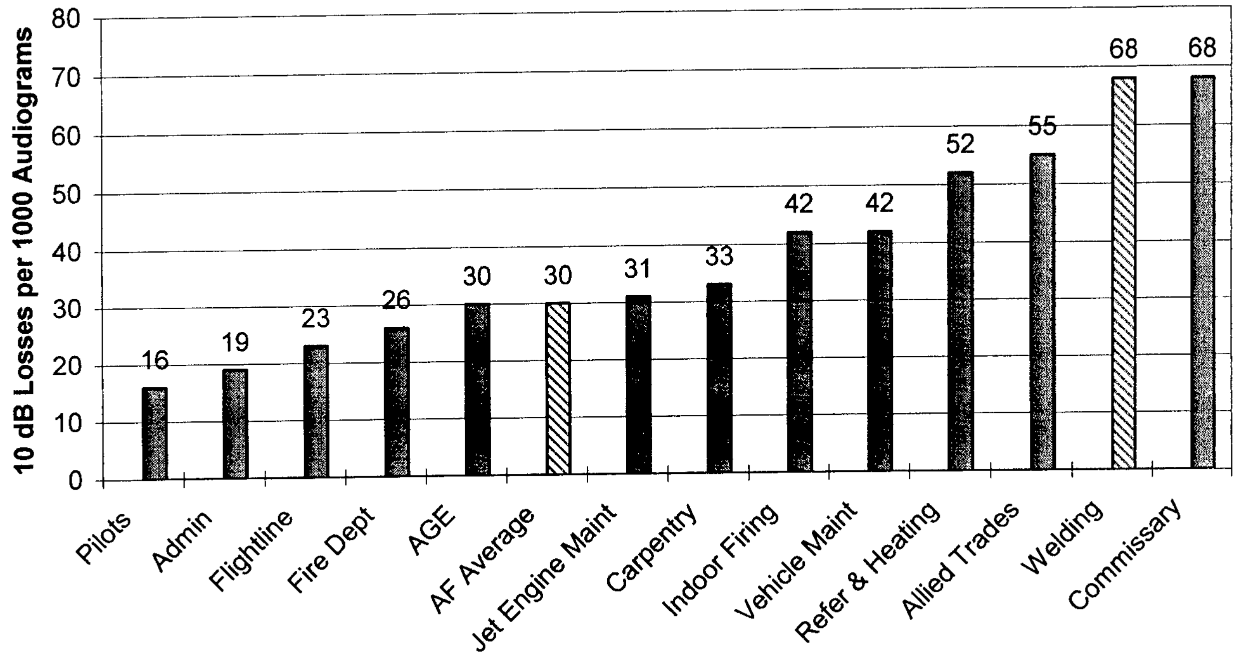
RATIONALE, HYPOTHESIS AND SCOPE

Rationale

Air Force welders suffer hearing loss at more than twice the rate of all Air Force personnel. Figure 1 is a graph of the hearing loss of Air Force personnel separated by functional area. The Air Force average is 30 - 10 dB losses per 1000 audiograms, but welders are experiencing 68 - 10 dB losses per 1000 audiograms.[2]

NIOSH issued a new noise criteria document in 1998 to facilitate a new noise standard. They determined that more research is required to determine the hazardous aspects of impulse noise. The aspects needing more research include, amplitude, duration, rise time, number of impulses, crest factor and repetition rate. Currently there is insufficient data to develop a damage risk criteria based on impulsive noise sources. NIOSH recommends integrating impulse noise with continuous noise even though there is research to indicate the combination of continuous noise and impulse noise may be more hazardous than each alone.[8]

Figure 1: Air Force Hearing Loss Incidence Rate by Job Function.



Hypothesis

Air Force welders are losing their hearing because they are not being adequately protected. They are not being adequately protected because the total energy of exposure due to impulsive noise that occurs during welding operations is not being efficiently characterized using existing equipment and protocols.

Objectives for evaluating welding operations:

1) Noise measurement equipment will be evaluated to assess radiofrequency interferences with measurement of exposure during welding operations.

2) Noise measurement sampling rates and averaging times will be assessed to determine if there are differences in the amount of total energy being characterized during routine exposure assessments.

Scope of Research

This project will be limited to assessing noise exposures to welders in several major types of welding which were SMAW, GMAW, FCAW, GTAW, OFC, PAC and AAC. Miscellaneous sources of hearing loss (ototoxins, non-occupational exposure, other noise sources and use of hearing protection) were not evaluated within this project.

CHAPTER 4

METHODS AND MATERIALS

4.0 Overview of Experimental Design

The basic experimental design followed the AIHA Exposure Assessment Model (Figure 2). Figure 3 is the AIHA model applied to welder noise exposures. This model was developed by AIHA to give Industrial Hygienists a framework for assessing occupational exposures.[34] Since there are so many types of welding with numerous variables for each type, it made sense to start with the SMAW and then add the other types after refining the data collection.

The overall sequence of steps was:

1) Assess current noise exposure measurement techniques
2) Assess the effect of EMF interference on measurement techniques
3) Develop and test new measurement techniques
4) Assess risk of hearing loss

Step one involves several issues. First, there are the two components of welder noise exposures (continuous and impulsive). There have been a number of studies suggesting different measurement techniques for assessing both the impulsive and continuous noise

component.[1,13,16,18,19,20] In general, a digital oscilloscope was the best method for impulse noise. Most standard equipment (sound level meters and noise dosimeters) was designed for and works well for continuous noise. Ideally, one sampling method for both would be best. The major limitation of a digital oscilloscope is the limited sampling duration. The major limitation of standard equipment is the limited response to impulse noise. One solution is to record the noise with analog or digital recorders and then replay the noise through both types of analyzers (oscilloscope and standard). Analog recorders have limited bandwidth and are not recommended for impulse noise. Digital recorders have adequate bandwidth, but may have problems with aliasing and their sampling rate may not be fast enough for short impulses. Aliasing is a distortion in the signal caused by not sampling at least twice as fast as the signal being studied.

The basic setup was to use a digital oscilloscope to record the combination of impulse and continuous noise. The measurement microphone was placed at ear level three feet from the welding operation. Data was collected via microphone, pre-amplifier, front-end unit and digital oscilloscope. The microphone converts the pressure to an electrical signal, which is boosted by the pre-amplifier. The front-end provides filtering (A, C and Flat weighting along with high pass filtering) and additional signal amplification (0 to 40 dB). The oscilloscope stores and displays the signal corresponding to the pressure signal. A calibration signal from an acoustical calibrator was run through the system before and after each data collection set. Calibration signal response can be used to determine the equivalent continuous sound pressure level, peak pressure level and estimated pulse

duration.[1] Additional equipment included a two real-time analyzers and digital recording equipment. Table 5 lists the measurement equipment used.

Table 5: Measurement Equipment and Instruments

	Manufacturer	Model/Type	Serial #	Cal Date
Microphones	Larson Davis Larson Davis	2530 2530	1031 1030	27 Feb 2002 27 Feb 2002
Pre-Amplifier	Norsonic	1201 1201	20083 20082	N/A
Front End Power Supply	Norsonic	336	20567	N/A
Digital Oscilloscope	High Techniques	FW8000-500	20002017	28 Jun 2002
DAT Recorder	Tascam	DA-P1	700146	N/A
Real Time Analyzer	Larson Davis	824	824A0320	N/A
Real Time Analyzer	Norsonic	840	18701	N/A
Calibrator	Quest	QC-20	QF8050049	1 Mar 2002

The second step was to determine the amount of electromagnetic interference with current measurements and come up with ways to eliminate or at least limit its effect on measurements. Electromagnetic fields can interfere with noise measurements, but most equipment only has interferences specified at power-line frequencies. The interference can be positive or negative, and several methods are suggested to assess interference. First, one must identify the suspect source during measurements. Next, one must assess

the magnitude of the interference in relation to the source being measured. If the magnitude of the interference is 5-10 dB less than the source, it may not be significant. One method for measuring the interference in a sound field is to use an inactivated acoustic calibrator over the microphone. The calibrator will typically provide 10 dB of attenuation. Calibrator attenuation can be tested in a similar sound field without the electromagnetic field present. Another method is to cover the microphone with plastic wrap and then cover it with clay. A dummy microphone can be also be used to detect interference. A final suggestion is move the microphone farther from the suspect source. This is only applicable to small electromagnetic sources where the fields can drop off dramatically within a few inches.[35] The effects of EMF interference were evaluated by using a two channel system, where one microphone was used normally and the other was varied by the various methods to evaluate the EMF interference effects. In general, channel 1 was used normally and channel 2 was used with the dummy microphone, calibrator or clay.

Step three was to combine the best techniques from step one to come up with a good technique to evaluate the total energy (using the EEH) from both the continuous and impulsive noise. Problems encountered included sampling rate and instrument response. A high sampling rate (especially on a digital oscilloscope) will shorten the time for samples considerably. A low sampling rate may miss some of the exposure. Several trials were run to optimize the sampling rate with the dose measured. The oscilloscope has a maximum sampling rate of 0.04 microseconds per point and a maximum storage capacity of 63 million points per sample. Collection time is limited to 0.2 seconds at the maximum sampling rate. This leads to a range of sampling rates to evaluate welding

noise exposures. The maximum sampling rate used was the maximum sampling rate of the oscilloscope while the slowest sampling rate was the standard slow response of 1 second. The slower sampling rates (slow, fast and impulse) were analyzed with a Larson Davis Real Time Analyzer (RTA). These samples were first collected on Digital Audio Tape (DAT) and then run through the RTA. The same data was also run through the oscilloscope and analyzed from 1 millisecond to 50 microseconds (1 to 20 kilohertz). A faster sampling rate could not be analyzed from the DAT because the DAT Recorder samples at 48,000 samples per second and faster analysis of this data could cause aliasing. Table 6 shows a list of sampling rates tested.

Table 6: Sampling Rates

Sampling Rate	Time (microseconds)
Maximum	0.04
Not defined	0.1
Not defined	0.2
Not defined	1
Not defined	2
Not defined	5
Not defined	10
Not defined	20
Not defined	50
Not defined	100
Not defined	200
Not defined	500
Not defined	1000
Impulse	35,000
Fast	125,000
Slow	1,000,000

Another problem with instrument response was the analyzer noise floors. Since the measurement system was setup to measure the high impulse levels, lower continuous levels were near the noise floor of the oscilloscope for some measurements. These

measurements were resampled and had their signals amplified by gain settings on the front end power supply. Other instrument settings that were optimized to get more reliable sampling were the weighting and high pass filters on the front end; the signal coupling in the oscilloscope (AC vs DC); and triggering on the oscilloscope. AC coupling with manual triggering was the most reliable.

Seven types of welding were evaluated. Table 7 is a list of the equipment tested and table 8 is a list of data runs. Data was primarily collected at Aims Community College (Greeley, CO) in the Welding Technology Lab. Mr. Eric Warren, a certified welder and instructor at Aims, operated all the welders and provided technical expertise on the welding operations. Additional data used for evaluating EMF interference was collected in a reverberation chamber at Brooks AFB. Noise floor testing was conducted in Fort Collins, CO.

Table 7: List of all Equipment Tested

Welding Process	Manufacturer	Name	Model	Serial #	Other
SMAW (Shielded Metal Arc Welding)	Thermal Arc	DC Inverter	260S	D92819A-103053	Rods 6010 – 95 Amps 7018 –115 Amps
SMAW	Hobart	Transformer	TR300	W520914	
GMAW (Gas Metal Arc Welding)	Thermal Arc Fabstar	Feeder Power Supply	2210 4030	T0080401004 T00071701168	Wire 0.0035 100% CO2 20V @ 120 Amps
FCAW (Flux Core Arc Welding)	Thermal Arc	Wire Feeder	400 GMS 17A	R02826A188607GOLF T00051301006	Wire 0.045 75% Argon 25% CO2 25V @ 180 Amps
GTAW (Gas Tungsten Arc Welding)	Thermal Arc		300 GTSW	0606303A18813F	Stainless Steel (DC) – 100 Amps 100% Argon Aluminum (AC) – 125 Amps
OFC (Oxy-Fuel Cutting)					8 psi Acetylene 40 psi O2
PAC (Plasma Arc Cutting)	Hypertherm	Power Max	380	#380-004696	20 Amps 80 psi
AAC (Air Carbon Arc Cutting)	Thermal Arc	Power Master	500	299PS21865	260 Amps

Table 8: Data Collection Sessions

Date	Media	Measurements	Location
20 Jun	Real Time Analyzer	EMF Testing	Brooks AFB
10 Jul	Digital Oscilloscope	SMAW	Aims
17 Jul	Digital Oscilloscope	GMAW FCAW TGAW	Aims
8 Aug	Digital Oscilloscope	SMAW PAC OFC	Aims
15 Aug	DAT Digital Oscilloscope	SMAW PAC OFC GMAW FCAW GTAW AAC AAC	Aims
28 Aug	Digital Oscilloscope DAT	GMAW GMAW	Aims
29 Sep	DAT	Noise Floor Testing	Lab
10 Oct	DAT	Noise Floor Testing	Lab
24 Oct	DAT	SMAW PAC OFC GMAW FCAW GTAW	Aims

Step four assessed the risk of hearing loss. A statistical model has been developed for predicting hearing thresholds (or their changes) of individuals or populations. It has been validated through numerous population databases and found to be reliable. Examples of the predicted hearing threshold levels are shown in Table 9. Levels are predicted based on exposure levels and years of exposure.[35] This model can be used to look at the predicted hearing loss for typical welder exposure levels.

Table 9: Predicted Noise Induced Permanent Threshold Shift (NIPTS) for Different Susceptibility Fractiles of the Population (Data are shown for three fractiles, 0.9 – tough ears, 0.5 – typical ears, and 0.1 - tender ears)[35]

Leq (dBA)	Freq (Hz)	20 Years of Exposure			40 Years of Exposure		
		.9	.5	.1	.9	.5	.1
90	500	0	0	0	0	0	0
	1000	0	0	0	0	0	0
	2000	2	4	8	4	6	10
	3000	7	10	16	9	12	19
	4000	9	13	18	11	15	20
	6000	4	8	14	6	10	15
95	500	0	0	1	0	1	1
	1000	2	3	5	2	3	6
	2000	5	9	17	9	14	22
	3000	13	19	31	18	23	37
	4000	16	23	32	19	26	36
	6000	8	16	26	12	19	29

$$HTLAN = NIPTS + HTLA - \left(\frac{NIPTS * HTLA}{120} \right)$$

Where HTLAN = total hearing threshold level associated with age and noise

NIPTS = noise-induced permanent threshold shift component

HTLA = age-related threshold component

And the last term is a correction factor to prevent over predicting at high levels of loss

Table 10: Age-Related Hearing Levels (HTLA) Expected from Presbycusis from a Normal Population. (Data are shown for three fractiles, 0.9 – tough ears, 0.5 – typical ears, and 0.1 - tender ears)[35]

Gender	Freq	Age 40 Years			Age 60 Years		
	(Hz)	.9	.5	.1	.9	.5	.1
Male	500	-5	2	11	-3	6	18
	1000	-5	2	11	-2	7	19
	2000	-6	3	15	-1	12	29
	3000	-5	6	19	3	20	42
	4000	-4	8	23	7	28	55
	6000	-5	9	26	8	32	62
Female	500	-5	2	11	-3	6	18
	1000	-5	2	11	-2	7	19
	2000	-5	3	13	-1	11	25
	3000	-5	4	15	0	13	30
	4000	-6	4	17	1	16	35
	6000	-6	6	21	2	21	45

An example of using this information would be to choose a hypothetical worker who is a 40-year-old male and has been exposed for 20 years at 90 dBA. Assuming the worker is an average (.5 fractile) worker, the NIPTS levels can be selected from Table 9 and the HTLA levels from Table 10. If we look at 4000 Hz, the worker would be expected to lose 13 dB from NIPTS and 8 dB from HTLA for a HTLAN of 21 dB. In this example, the correction factor is less than 1 dB.

Figure 2: AIHA Exposure Assessment Model

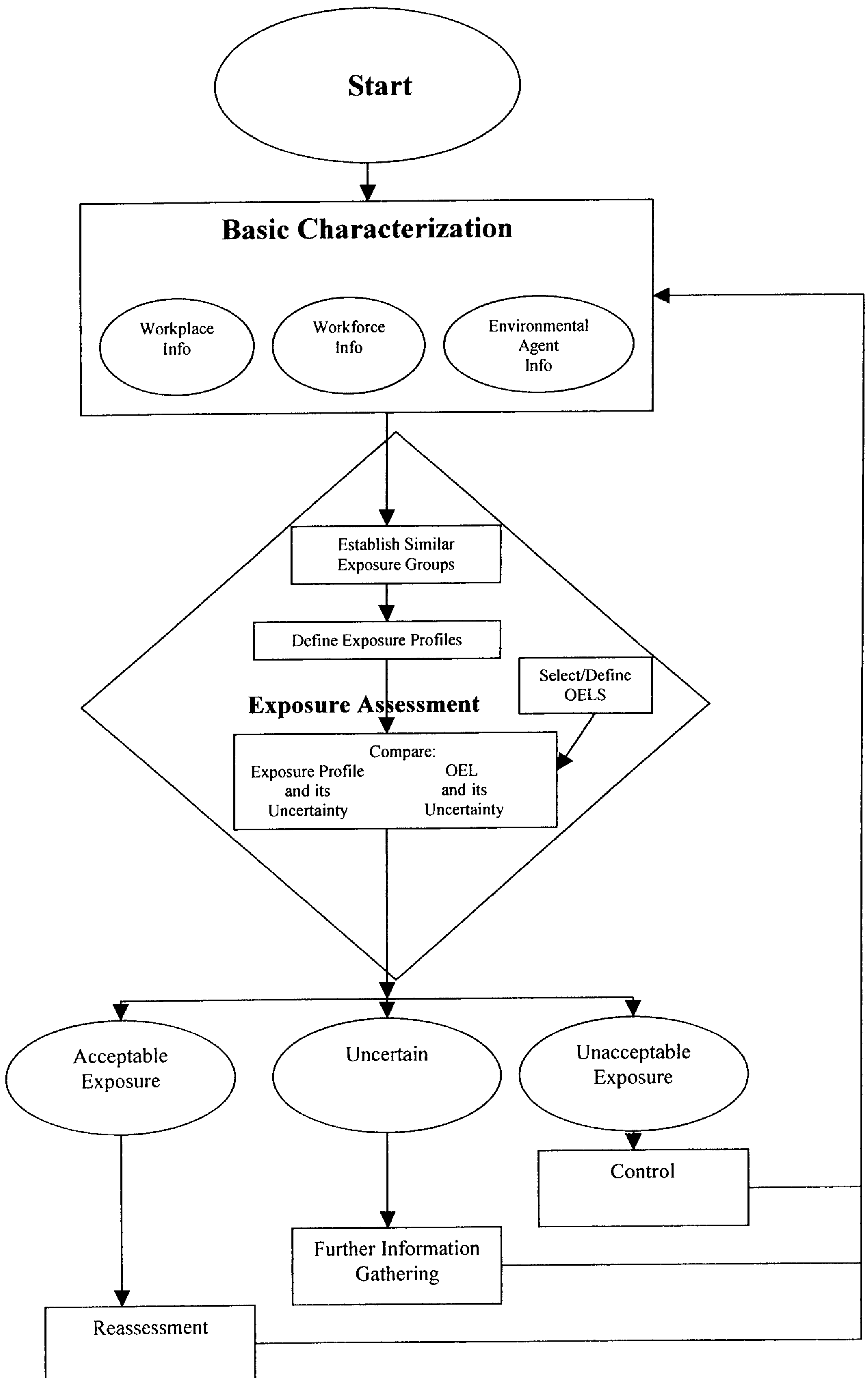
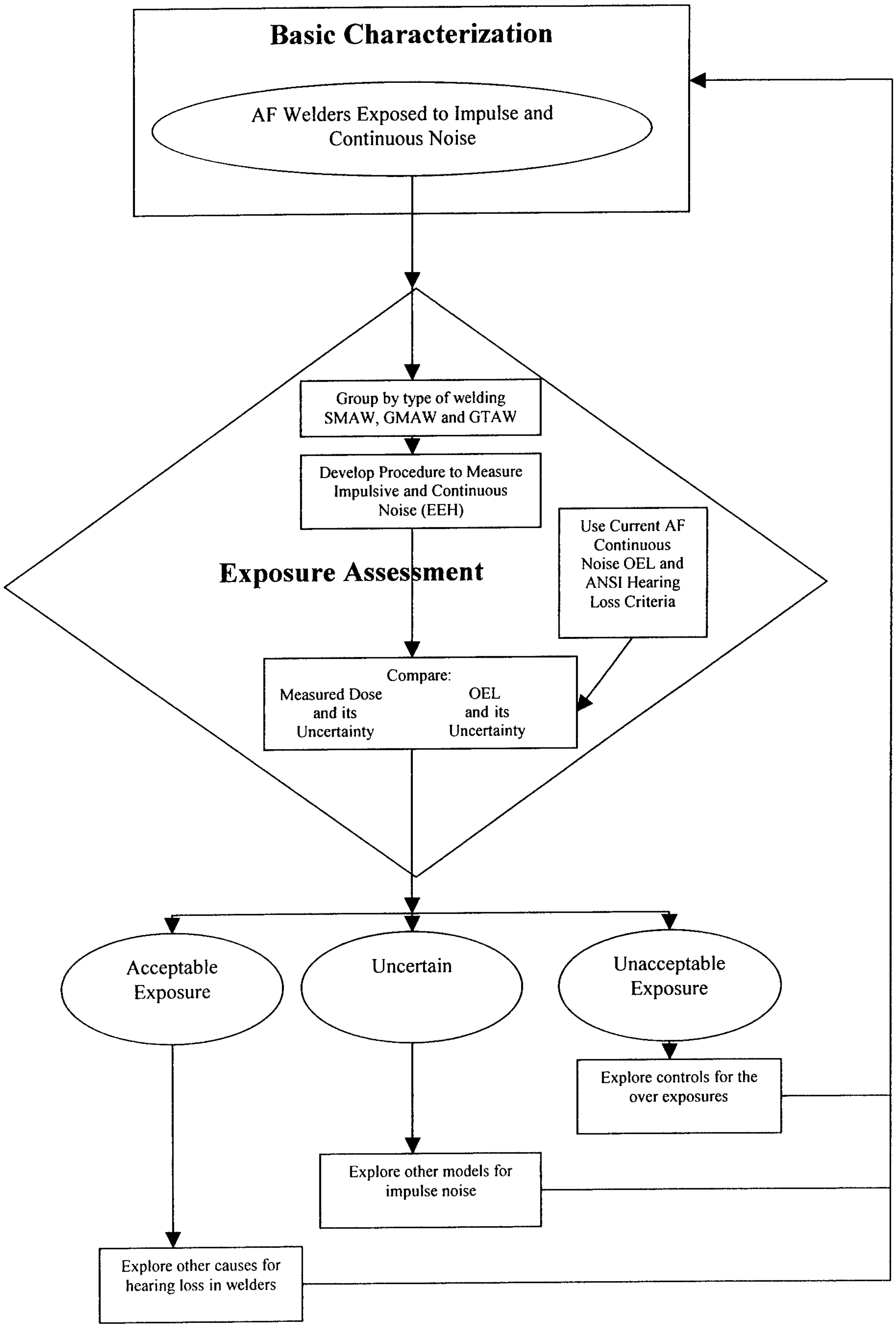


Figure 3: AIHA Exposure Assessment Model Applied to Welding Exposures



CHAPTER 5

RESULTS AND DISCUSSION

5.0 Results and Discussion

The results are presented and discussed in three major sections. The first is EMF interference with measurements. The next is the noise exposure measurements and last is predicted hearing loss levels.

5.1 EMF Interference

The EMF interference section is also discussed in three sections. The first section deals with techniques testing in a reverberation chamber. The next section reviews results from measurements collected on a DAT and then analyzed on a RTA. The last section reviews results collected and analyzed on a digital oscilloscope. The two main techniques used were an inactivated calibrator and a dummy microphone. The inactivated calibrator attenuates the signal reaching the microphone. The dummy microphone replaces the microphone with an electrical short; therefore any signal measured is either from EMF interference or the electrical background (noise floor) of the instrumentation.

5.1.1 Reverberation Chamber Measurements

The EMF interference on the measurement techniques was first tested in a reverberation chamber at Brooks AFB. A reverberation chamber is designed to provide a uniform sound field. After testing in the reverberation chamber, the methods were field tested in a welding technology laboratory at Aims Community College.

Figure 4 and Tables 11-14 show the results of method testing in the reverberation chamber. These data were analyzed by running the signal from the front-end unit directly into a real time analyzer. Figure 4 shows the inactivated calibrator provided good attenuation from 500 Hz to 16000 Hz with an overall attenuation of over 20 dBA. Below 500 Hz the calibrator provided little attenuation. This same data is shown in tabular form in Table 11. It shows that for low frequencies the calibrator is not very effective and may even have a negative effect possibly from resonance of the calibrator. Also, the background levels (Table 13) were fairly high at 16 and 31.5 Hz. Table 12 shows that the clay was very effective at frequencies above 4000 Hz, but overall was not very effective providing less than 10 dBA of attenuation. In this setup 12 oz. of clay was used. Several pounds were recommended, but could not be used in this setup. Table 13 shows the background levels in the reverberation chamber. The background levels in the chamber were well below the measurement levels (Table 14) except at the low frequencies of 16 and 31.5 Hz. Table 14 shows the differences between the two channel setups. Overall the differences were about 1 dB at all but the low frequencies, which were affected by background levels. The speaker system used to create the sound field could not produce much intensity at the low frequencies. In addition, reverberation chambers do not work

as well at low frequencies because the long wavelengths make creating a uniform sound field very difficult.

Figure 4: Noise Attenuation of Calibrator in Reverberation Chamber.

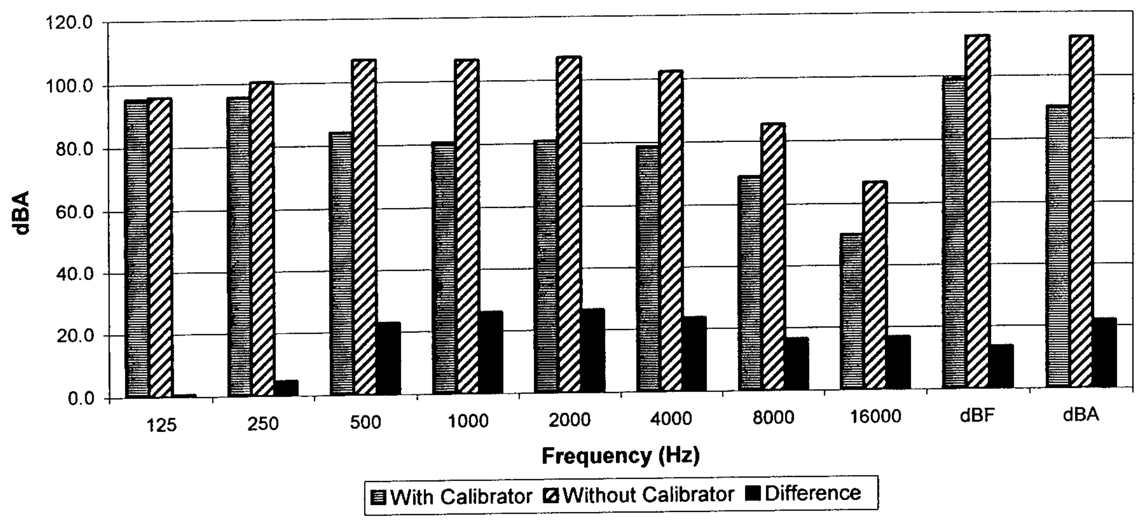


Table 11: Noise Attenuation of Calibrator in Reverberation Chamber.

Table 11			
Ch1: With Calibrator		Ch2: W/O Calibrator	
Freq (Hz)	Leq(dB)	Leq(dB)	Difference
16	80.8	62.8	-18.0
31.5	73.4	68.1	-5.3
63	84.2	75.8	-8.4
125	95.2	95.8	0.6
250	95.7	100.4	4.7
500	84.1	107.0	22.9
1k	80.6	106.6	26.0
2k	80.7	107.1	26.4
4k	78.7	102.3	23.6
8k	68.8	85.3	16.5
16k	49.9	66.7	16.8
dBF	99.0	112.5	13.5
dBA	90.2	112.1	21.9

Table 12: Noise Attenuation of Clay in Reverberation Chamber.

Table 12			
Ch1: With Clay		Ch2: W/O Clay	
Freq (Hz)	Leq(dB)	Leq(dB)	Difference
16	66.8	63.8	-3.0
31.5	74.8	72.3	-2.5
63	94.7	77.0	-17.7
125	104.2	95.9	-8.3
250	97.3	100.3	3.0
500	101.3	106.8	5.5
1k	99.8	106.7	6.9
2k	97.9	107.1	9.2
4k	88.1	102.3	14.2
8k	69.1	85.3	16.2
16k	44.3	66.6	22.3
dBF	108.0	112.5	4.5
dBA	104.3	112.1	7.8

Table 13: Background Levels in Reverberation Chamber.

Table 13			
Ch1: Normal		Ch2: Normal	
Freq (Hz)	Leq(dB)	Leq(dB)	Difference
16	73.2	61.5	-11.7
31.5	64.9	58.6	-6.3
63	54.5	51.4	-3.1
125	44.9	41.9	-3.0
250	39.9	38.7	-1.2
500	38.2	36.8	-1.4
1k	37.6	36.2	-1.4
2k	38.4	37.1	-1.3
4k	38.3	37.3	-1.0
8k	40.0	39.2	-0.8
16k	42.7	42.1	-0.6
dBF	69.1	61.2	-7.9
dBA	46.2	45.0	-1.2

Table 14: Side-by-Side Measurements in Reverberation Chamber.

Table 14			
Ch1: Normal		Ch2: Normal	
Freq (Hz)	Leq(dB)	Leq(dB)	Difference
16	73.5	62.0	-11.5
31.5	70.7	64.8	-5.9
63	76.0	75.6	-0.4
125	95.2	95.5	0.3
250	100.6	100.5	-0.1
500	106.4	106.7	0.3
1k	105.7	106.6	0.9
2k	107.0	107.2	0.2
4k	101.5	102.3	0.8
8k	84.9	85.3	0.4
16k	65.2	66.5	1.3
dBF	112.0	112.4	0.4
dBA	111.6	112.1	0.5

Based on these findings the use of a two-channel set up in the field was demonstrated to be an effective assessment tool.

5.1.2 DAT to RTA EMF Results

These data were collected with the two-channel system and stored on digital audiotape and then analyzed with a real time analyzer. The rule of thumb is that if the interference is 10 dB less than the signal of concern then no correction is needed. If there is 5 to 10 dB difference, then some correction may be needed. The calibrator provided 10-15 dBA of attenuation. The dummy microphone was very effective at showing the EMF interference was not appreciable by providing 30 to 40 dB of attenuation in most cases. The exception was for SMAW where only 17 to 22 dB of attenuation was noted. Table 17 shows side-by-side measurements with the two-channel system. These side-by-side measurements were collected at the same time as the EMF interference measurements for the calibrator and dummy microphone. They show less than a 1 dB difference in all

cases. This indicates the two channels had no significant differences in looking at the EMF interference measurements.

Table 15: EMF Interference Measurements for Seven Types of Welding.

Table 15	Leq (dB)		
	Microphone Setup		
Measurement	Normal	With Calibrator	Delta
SMAW (60/10)	77.0	63.0	14.0
SMAW (70/18)	76.5	62.1	14.4
PAC	86.4	76.6	9.8
OFC	74.5	59.0	15.5
GMAW	88.6	75.1	13.5
FCAW	76.5	61.2	15.3
GTAW (ST)	73.4	59.1	14.3
GTAW (AL)	79.0	63.6	15.4
AAC	102.9	83.2	19.7

Table 16: EMF Interference with Dummy Microphone for Seven Types of Welding.

Table 16	Leq (dB)		
	Microphone Setup		
Measurement	Normal	With Dummy	Delta
SMAW (60/10)	77.3	55.4	21.9
SMAW (70/18)	76.0	59.3	16.7
PAC	87.0	39.3	47.7
OFC	72.6	39.2	33.4
GMAW	88.1	39.2	48.9
FCAW	75.5	38.1	37.4
GTAW (ST)	73.1	39.5	33.6
GTAW (AL)	79.7	39.2	40.5
AAC	102.1	63.5	38.6

Table 17: Side-by-Side DAT to RTA Measurements.

Table 17	Leq (dB)		
	Microphone Setup		
Measurement	Normal	Normal	Delta
SMAW (60/10)	77.2	77.2	0.0
SMAW (70/18)	76.2	76.1	0.1
PAC	85.6	85.3	0.3
OFC	74.4	74.2	0.2
GMAW	90.0	90.2	-0.2
FCAW	76.8	77.6	-0.8
GTAW (ST)	73.4	73.3	0.1
GTAW (AL)	80.6	80.1	0.5
AAC	104.2	104.6	-0.4

5.1.3 Digital Oscilloscope EMF Results

This data was collected by capturing and analyzing the signal on a digital oscilloscope. The oscilloscope results for EMF interference did not come out near as well as the DAT to RTA results. The primary cause for these poor results was the high noise floor of the oscilloscope. The front-end unit had possible gains of 0 to 40 dB in 10 dB steps. For the setups used, the noise floor was 99 dB for 0 dB gain, 89 for 10 dB gain, 80 for 20 dB gain, 70 for 30 dB gain and 63 for 40 dB gain. Twenty or 30 dB of gain was used for most measurements. Because of distortion concerns at the highest gain setting of 40 dB this setting was not used (note that the noise floor did not drop 10 dB for the higher gain setting). In addition, some of the peaks would overload the instrument at the higher gain settings even though the overall signal was not that high. This behavior is evident in tables 18 and 19, which show the EMF interference with the oscilloscope measurements. These results show that when using the digital oscilloscope, sufficient attenuation could not be achieved relative to the noise source to reliably assess EMF interference.

Table 18 shows the EMF interference for the oscilloscope measured with the calibrator. The noise floor for the oscilloscope was too high for most of the measurements for the calibrator to be used effectively. Only AAC had attenuation greater than 10 dB. PAC, GMAW and FCAW were in the 5 to 10 dB range. Table 19 shows the EMF interference of the oscilloscope measured with the dummy microphone. Once again the noise floor for the oscilloscope was too high for most of the measurements for the dummy microphone to be used effectively. Only PAC, GMAW and AAC had attenuation greater than 10 dB. SMAW, FCAW and GTAW were in the 5 to 10 dB range. Table 20 shows side-by-side oscilloscope measurements. They were collected at the same time as the EMF interference measurements for the calibrator and dummy microphone. The show less than a 2 dB difference in all cases. This indicates the two channels had no significant differences in looking at the EMF interference measurements.

Table 18: EMF Interference for the Oscilloscope Measured with the Calibrator.

Table 18	Leq (dB)		
	Microphone Setup		
Measurement	Normal	With Calibrator	Delta
SMAW	87.8	83.9	3.9
PAC	93.7	88.2	5.5
OFC	87.6	85.0	2.6
GMAW	92.7	86.6	6.1
FCAW	80.0	74.8	5.2
GTAW (ST)	75.8	74.0	1.8
GTAW (AL)	79.1	74.9	4.2
AAC	103.5	89.8	13.7

Table 19: EMF Interference for the Oscilloscope Measured with the Dummy microphone.

Table 19	Leq (dB)		
	Microphone Setup		
Measurement	Normal	With Dummy	Delta
SMAW	89.5	84.0	5.5
PAC	95.9	84.0	11.9
OFC	87.8	84.9	2.9
GMAW	97.1	84.0	13.1
FCAW	81.3	74.0	7.3
GTAW (ST)	75.2	73.6	1.6
GTAW (AL)	79.5	74.0	5.5
AAC	104.9	84.3	20.6

Table 20: Side-by-Side Oscilloscope Measurements.

Table 20	Leq (dB)		
	Microphone Setup		
Measurement	Normal	Normal	Delta
SMAW	87.7	88.6	-0.9
PAC	93.2	93.2	0.0
OFC	87.9	86.5	1.4
GMAW	95.6	95.6	0.0
FCAW	82.9	81.5	1.4
GTAW (ST)	74.7	75.3	-0.6
GTAW (AL)	80.3	80.2	0.1
AAC	101.7	102.2	-0.5

Figures 5, 6 and 7 are of Gas Metal Arc Welding (GMAW) and were sampled and analyzed using a digital oscilloscope. Measurements were collected side by side, with a calibrator and with a dummy microphone. Figure 5 shows good signal duplication between the two channels. Figure 6 shows the dummy microphone eliminated the peak signals but there is some EMF interference present. Figure 7 shows the peaks are still present but have been attenuated by the calibrator.

Figure 5: Gas Metal Arc Welding (GMAW) Side-by-Side Measurements.

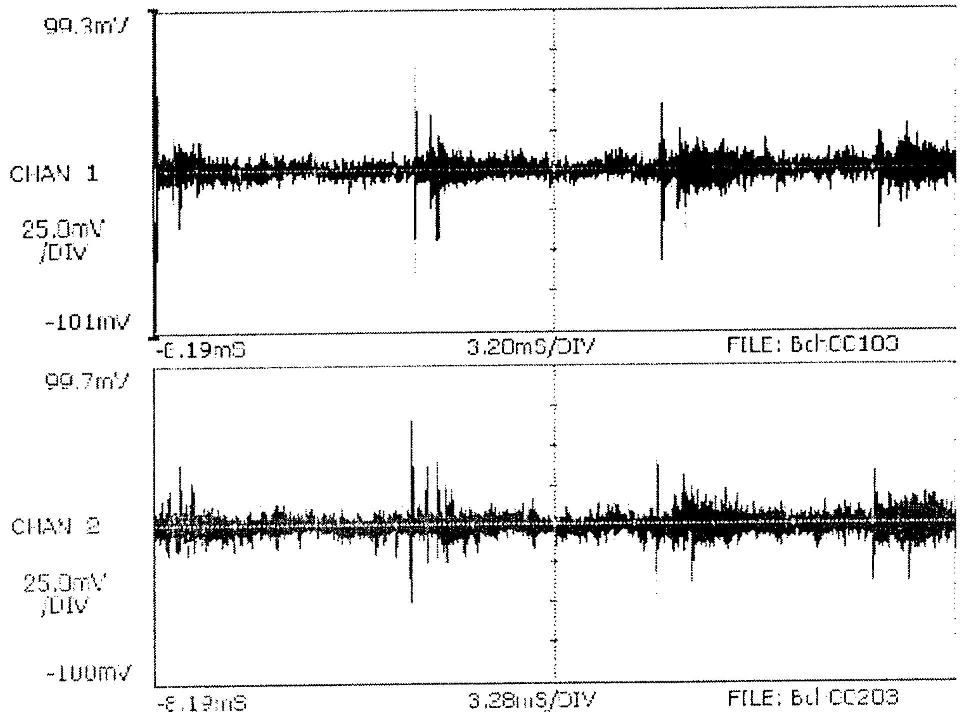


Figure 6: GMAW with Dummy Microphone on Channel 2.

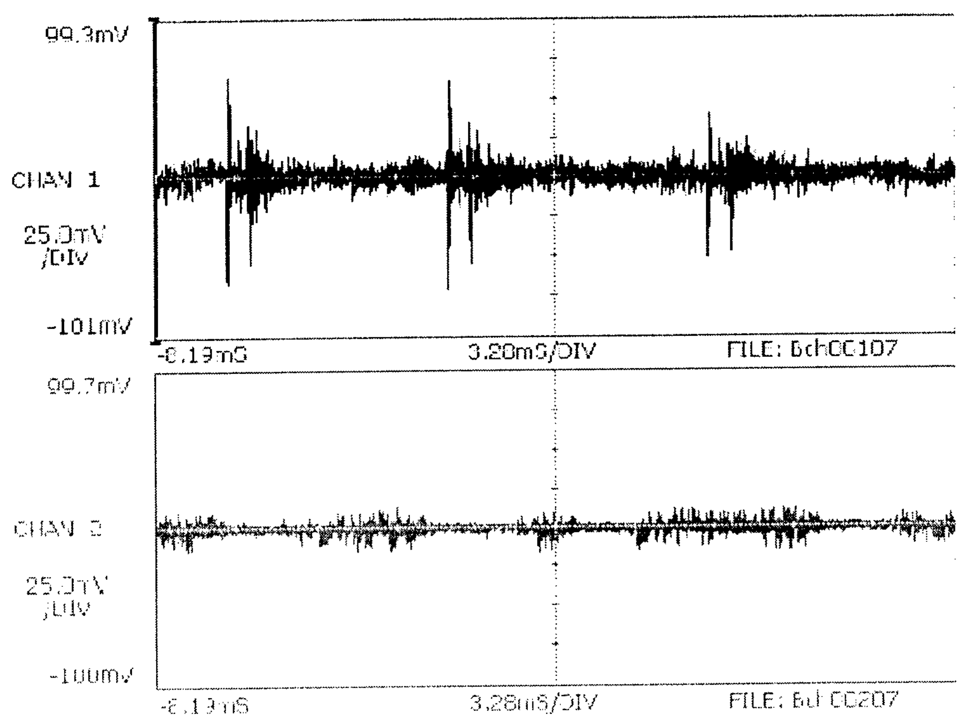
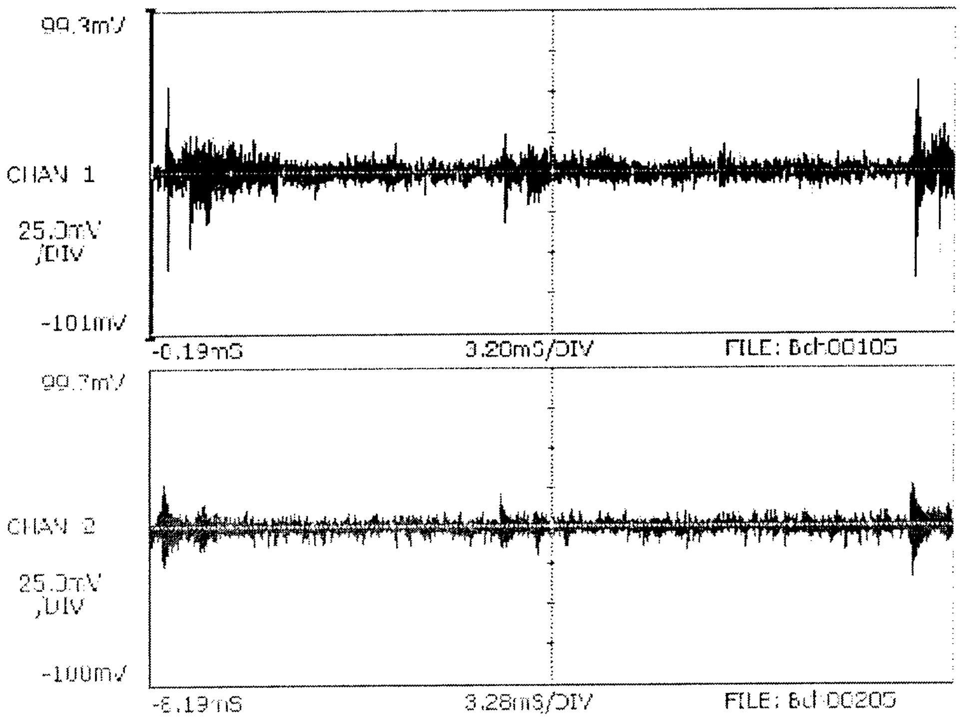


Figure 7: GMAW with Calibrator on Channel 2.



In general, EMF interference was not as easy to evaluate for the samples that were collected and analyzed on the digital oscilloscope. The noise floor for the oscilloscope was too close the to the actual measurement levels. Gas Metal Arc Welding, Plasma Arc Cutting and Air Arc Carbon Cutting were high enough above the noise floor to have their EMF interference evaluated with the dummy microphone. Only AAC was high enough above the noise floor to be effectively evaluated with the calibrator. The waveform graphs of the GMAW measurements showed good replication of the side-by-side measurements. They also showed the effectiveness of the dummy microphone in eliminating the peaks, but some EMF interference was present. The calibrator also attenuated the peaks.

5.1.4 EMF Results Summary

The results showed an inactivated calibrator was effective in evaluating interference levels. The inactivated calibrator provided 10 to 15 dBA of attenuation in the frequency range of 500 Hz to 16 kHz. The clay method showed promise, but it was not effective for this equipment setup and provided less than 10 dBA of attenuation. As expected, the dummy microphone was very effective and provided attenuation of at least 17 dBA for all types of welding. Some interference was noticeable on Gas Metal Arc Welding even with the use of a dummy microphone.

In summary, for most cases the interference is not significant but EMF interference does effect some welder noise exposure measurements as shown in Figure 7 and previous studies[1] and therefore should be assessed when conducting welder noise exposure measurements.

5.2 Exposure

Welder exposure measurements were collected and analyzed by three different methods. The first method was by collecting the signal on DAT and then analyzing it with a Real Time Analyzer (RTA). The second method used the signal already collected on the DAT and analyzed it with a digital oscilloscope. The last method was to collect and analyze the signal with the digital oscilloscope. The three methods allowed for a range of sampling rates to be used. The first method used standard slow, fast and impulse sampling rates. The second method sampled from 1 to 20 kHz. The last method sampled from 10 kHz to 25 MHz.

Overall levels from the first method are presented first. Results are presented for maximum levels, dBA, dBC and dBF. In addition the signals are broken down by frequency spectrum. Next the different methods and sampling rates are presented individually and then combined into a summary graph.

5.2.1 First Method: DAT to RTA Data

Tables 21-24 are from measurements at Aims collected on DAT and then analyzed with the RTA. Typical industrial hygiene measurements would be collected as dBA with the instrument set at slow response. Most standard sound level meters can also collect measurements as dBC and at fast response. The Lmax measurements in Table 21 show the maximum levels measured during each interval with the different sampling rates. The three processes highlighted showed promise for proving the hypothesis since they all increased their level with faster sampling rate. Table 22 shows Leq (Slow) measurements. These measurements are typical of measurements collected with a standard sound level meter. The dBA and dBC values are compared to dBF, because dBF was used for the digital oscilloscope measurements. This allowed the measurements to be compared more directly. Table 23 shows Leq (dBA) measurements for different sampling rates. These measurements compared the different sampling rates available for the RTA. Based on the hypothesis the levels should have gone up with the faster sampling rates, but they did not. They varied less than a few tenths of a dBA in all cases. The instrumentation setup fits a Type 1 criterion that roughly has +/-1 dB accuracy.[35] This means the differences are insignificant. Table 24 is similar to Table 23 except dBF

instead of dBA was used. Once again the levels varied less than a few tenths of a dBA in all cases. These differences are also insignificant.

Table 21: Lmax Measurements from DAT to RTA.

Table 21	Lmax (dBA)		
	Instrument Response		
Measurement	slow	fast	impulse
SMAW (60/10)	79.2	78.6	79.5
SMAW (70/18)	77.7	78.1	79.9
PAC	87.3	86.8	87.1
OFC	76.0	77.9	78.2
GMAW	91.9	94.5	97.4
FCAW	78.8	84.2	87.5
GTAW (ST)	75.6	74.5	75.3
GTAW (AL)	82.6	84.4	84.9
AAC	105.5	106.3	106.7

Table 22: Leq (Slow) Measurements for DAT to RTA.

Table 22	Leq (Slow)		
	Instrument Weighting		
Measurement	dBA	dBC	dBF
SMAW (60/10)	77.2	82.0	83.0
SMAW (70/18)	76.2	81.7	82.6
PAC	85.6	84.5	90.7
OFC	74.4	77.8	79.3
GMAW	90.0	89.3	92.8
FCAW	76.8	81.3	82.3
GTAW (ST)	73.4	80.1	80.8
GTAW (AL)	80.6	82.4	84.7
AAC	104.2	102.6	104.4

Table 23: Leq (dBA) Measurements for DAT to RTA.

Table 23	Leq (dBA)		
	slow	fast	impulse
SMAW (60/10)	77.2	77.4	77.4
SMAW (70/18)	76.2	76.3	76.3
PAC	85.6	85.6	85.6
OFC	74.4	74.5	74.5
GMAW	90.0	90.0	90.0
FCAW	76.8	77.1	76.8
GTAW (ST)	73.4	73.4	73.4
GTAW (AL)	80.6	80.7	80.7
AAC	104.2	104.1	104.2

Table 24: Leq (dBF) Measurements for DAT to RTA.

Table 24	Leq (dBF)		
	slow	fast	impulse
SMAW (60/10)	83.0	83.0	83.0
SMAW (70/18)	82.6	82.6	82.6
PAC	90.7	90.6	90.7
OFC	79.3	79.3	79.3
GMAW	92.8	92.8	92.8
FCAW	82.3	82.4	82.3
GTAW (ST)	80.8	80.9	80.8
GTAW (AL)	84.7	84.8	84.7
AAC	104.4	104.3	104.4

5.2.1.1 Octave Band Data

Table 25 and figures 9 and 10 show octave data for the different welding types. The octave band data is valuable for seeing where the energy is present in a signal. This can then be used to plan for engineering controls and evaluate the effectiveness of hearing protective devices. Table 25 shows the frequency spectrums for typical measurement for each welding type and the overall dBA and dBC levels.

Table 25: Octave Band Measurements for DAT to RTA.

Table 25	Octave Bands (Hz)												
Measurement	16	31.5	63	125	250	500	1000	2000	4000	8000	16000	dBA	dBC
SMAW (60/10)	72.6	74.3	75.5	77.9	70.2	71.6	70.1	69.2	69.7	70.2	70.4	77.2	82.0
SMAW (70/18)	71.3	72.8	75.5	77.7	70.4	71.5	69.9	68.3	67.8	67.9	69.4	76.2	81.7
PAC	71.5	70.9	73.0	71.3	66.1	64.5	65.0	72.2	77.6	82.9	88.8	85.6	84.5
OFC	72.6	70.8	72.6	70.9	65.1	64.5	63.9	68.3	67.7	68.8	69.0	74.4	77.8
GMAW	70.9	72.7	75.8	78.8	77.8	74.1	74.9	78.3	84.0	87.6	88.5	90.0	89.3
FCAW	71.8	72.7	75.1	76.0	71.8	70.5	70.1	69.0	68.7	69.6	70.6	76.8	81.3
GTAW (ST)	70.7	72.8	73.8	75.9	70.6	70.7	68.4	65.8	60.2	53.3	50.9	73.4	80.1
GTAW (AL)	70.1	73.9	74.0	75.9	70.6	71.1	69.7	71.1	72.7	77.8	78.9	80.6	82.4
AAC	---	37.7	50.9	60.1	66.9	80.0	89.9	98.1	101.0	98.0	89.9	104.2	102.6

When the energy is centered near 1000 Hz then the overall dBA and dBC values will be similar. If the dBC value is much larger than the dBA value then the energy is primarily from low frequency sources. If the dBC value is less than the dBA value then the energy is primarily from middle to high frequency sources. Figures 8 and 9 are graphs of two examples. Figure 8 shows an example where dBA and dBC are nearly equal. The octave band spectrum is dominated by high frequency energy. Figure 9 has a spectrum where the energy is primarily in the low frequencies and dBC is higher than dBA.

Figure 8: Graph of Gas Metal Arc Welding (GMAW) Octave Band Spectrum.

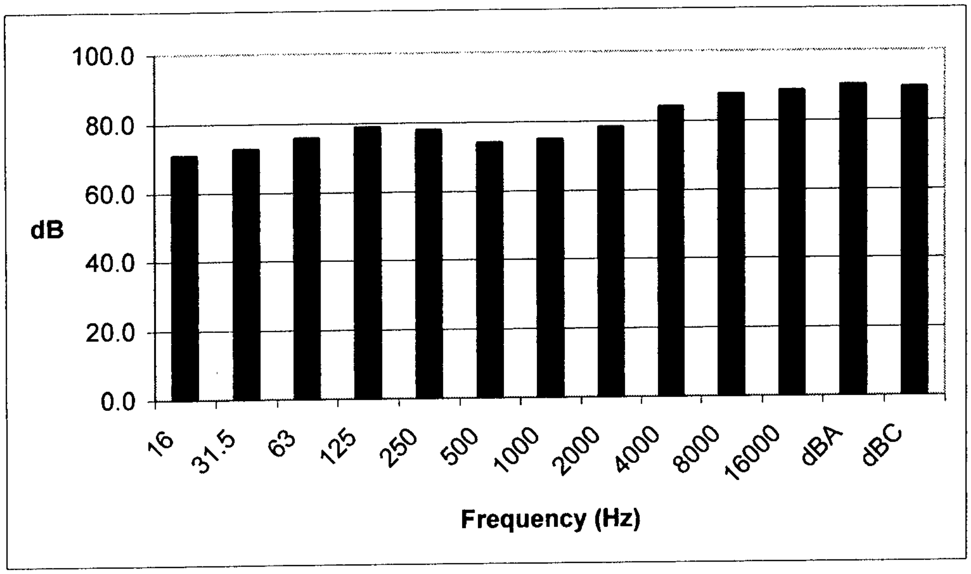
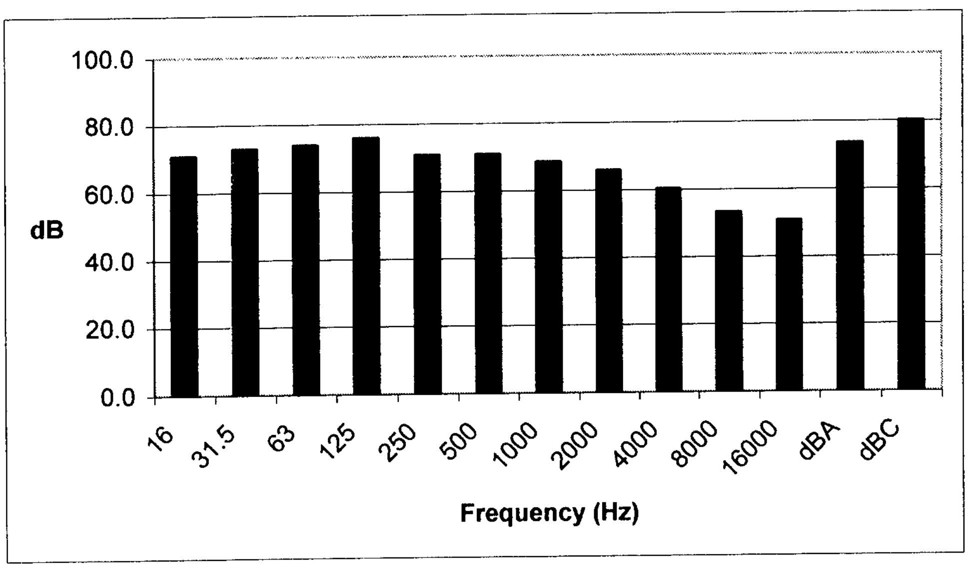


Figure 9: Graph of Gas Tungsten Arc Welding (Steel) Octave Band Spectrum.



5.2.2 Second Method: DAT to Digital Oscilloscope Data

To get slightly higher sampling rates than the RTA, data was taken from the DAT and run into the oscilloscope. The sampling rate was limited to 20 kHz because the DAT

samples at 48 kHz and faster sampling could cause aliasing. Each measurement for a welding type was rerun repeatedly at each sampling rate. The hypothesis would predict the levels to increase with sampling rate. These measurements showed very little change by changing the sampling rate for individual measurements. The levels did not increase as predicted.

Table 26: Decibel Levels for Changing Sampling Rate on DAT to Oscilloscope.

Table 26	dBF								
Sampling Rate	SMAW (60/10)	SMAW (70/18)	PAC	OFC	GMAW	FCAW	GTAW (ST)	GTAW (AL)	AAC
20K	83.4	83.7	90.7	79.9	92.9	82.9	81.5	85.1	106.0
10K	83.5	83.6	90.6	80.0	92.1	82.9	81.4	85.1	106.0
5K	83.3	83.7	90.6	79.9	92.9	83.0	81.5	85.0	106.0
2K	83.4	83.7	90.6	80.1	92.8	83.0	81.6	84.7	106.0
1K	83.4	83.6	90.8	80.1	93.0	83.2	81.5	84.8	106.3

5.2.3 Third Method: Digital Oscilloscope Data

To achieve higher sampling rates the data was collected and analyzed with the oscilloscope. Based on the hypothesis the levels should increase with higher sampling rates. Because of the high noise floors with the oscilloscope only the data for GMAW and AAC is presented. Both of these types of welding were at least 10 dB higher than the noise floor. Table 27 shows the data numerically. These measurements showed more variability than the DAT to Oscilloscope measurements because each sample is from a different point in time. Therefore, there are two forms of variability (sampling rate and source variability). No increasing trend was present as predicted from the hypothesis.

Table 27: Decibel Levels for Changing Sampling Rate on Oscilloscope Measurements.

Table 27	dB	
Sampling Rate	GMAW	AAC
10k	93.3	105.0
20k	92.7	106.9
50k	91.6	105.4
100k	92.4	104.4
200k	91.4	104.4
500k	91.5	104.6
1M	90.7	101.9
5M	94.5	105.5
10M	87.3	103.3
25M	89.7	104.3

5.2.4 Summary Data (All Three sampling methods together)

To better visualize the data from the three sampling methods, the data are presented in a graphical form in figures 10 and 11. There is no apparent increasing trend as was predicted. The DAT to RTA and DAT to oscilloscope measurements were all analyzed from the same sample by replaying the tape with different analysis parameters. The oscilloscope data are from separate measurements and hence had additional variability introduced. Figures 10 and 11 show little variability between points and no increasing trend with sampling rate.

Figure 10: Graph of All Three Sampling Methods for GMAW.

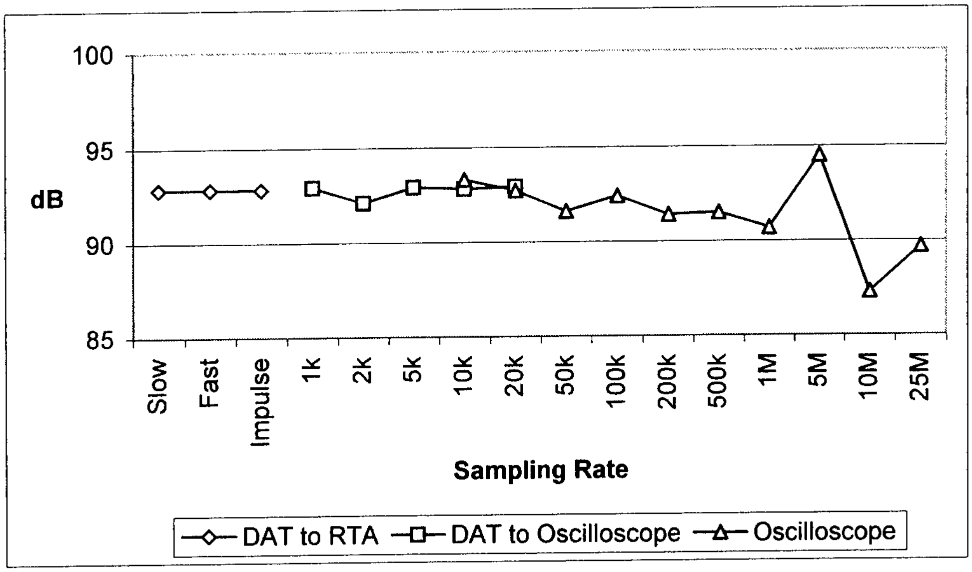
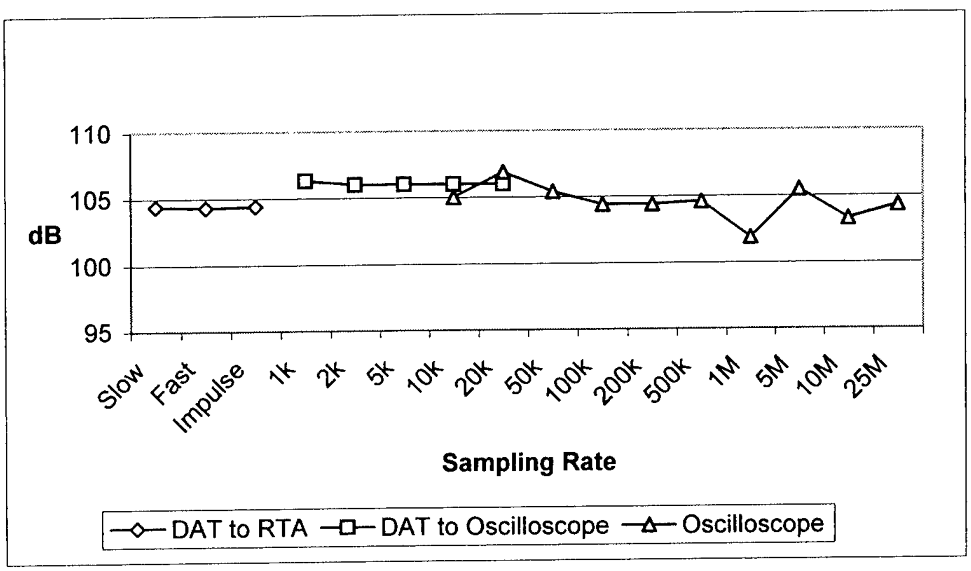


Figure 11: Graph of All Three Sampling Methods for AAC.



5.2.5 Conclusions on Exposure/Sampling Rate

Increasing the sampling rate did not increase the dose as expected. The peak area under the curve of SPL versus time appears to be too small to affect the overall energy using the

Equal Energy Hypothesis. This addresses the objective of discovering unrecorded exposure by varying the sampling rate.

5.3 Results for Hearing Loss

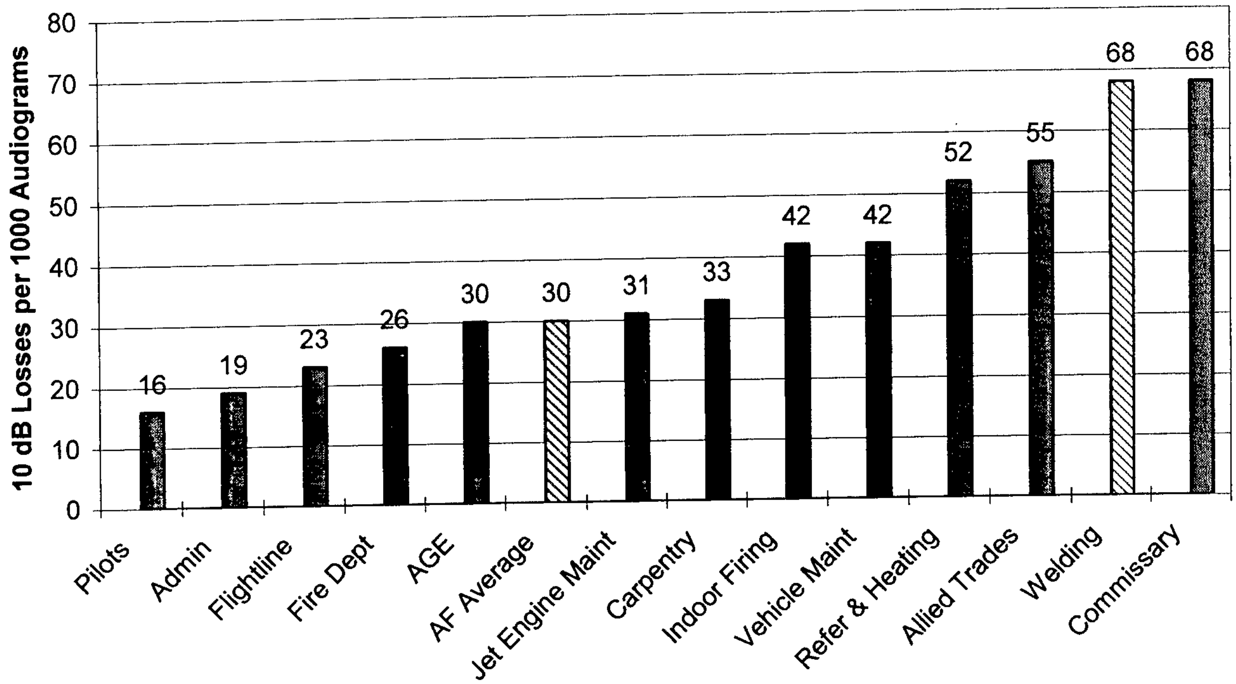
The next step was to assess the risk of hearing loss for the welders. This portion of the research was further broken down into three parts. The first part was to reexamine the incidence rate of AF welder's hearing loss. The next step was to look at welder noise exposures from other studies and finally to look at predicted hearing loss based on an ANSI Model.

5.3.1 Hearing Loss Incidence Rate for AF Welders

Figure 12 (same as Figure 1) shows the hearing loss incidence rate for various AF occupational specialties. Welding had an incidence rate of 6.8% versus 3% for the AF average. This data was based on a 1995 study. Incidence rates of 3 to 6% are considered reasonable for effective Hearing Conservation Programs (HCPs).[8] There are number of disadvantages of using incidence rates for looking at the effectiveness of HCPs. Incidences rates are not adjusted for several major sources of variability in hearing loss. These variables include age, sex, race and exposure level. Since the rates are not adjusted (for age, sex, race and exposure level), it makes them difficult to compare across industries. Another suggested method is to compare the incidence rates to an unexposed population within the same company, which presumably would have similar age, sex and race characteristics to the exposed population. In Figure 12, the unexposed population is the administrative group, which had an incidence rate of 1.9%. Based on this method, the

AF average of 3% seems a reasonable incidence rate since it is only 1% higher than the unexposed population.

Figure 12: Air Force Hearing Loss Incidence Rate by Job Function.



There is limited audiometric data currently available for AF workers. The AF Hearing Conservation Data Registry was combined with other services at the Department of Defense level and turned over to a contractor. Unfortunately, there was poor contractor performance and after two contractors were terminated, the current contractor is trying to validate the data in the system from the previous contractors. Data are just now becoming available. Summary data were obtained for AF welders and Air Force averages, but individual audiometric records are still not available. This limited the amount of analysis that could be done. In addition, the definitions for hearing loss

incidence rates have changed. Summary data from 1991 to 1999 were pulled from the system and are presented in Figure 13 and Table 28. The 1995 data, which should be the same as Figure 12, shows an AF incidence rate of 21% (vs. 3%) and the welder incidence rate is 46% vs. (6.8%). These changes are a result in a change in the definition of what constitutes a hearing loss. If you compare the ratios of these two incidence rates you get ratios of 2.2 and 2.3 times the AF average for welders. The lack of individual data does not allow the determination of standard deviations for the rates, but the AF average was based on approximately 100,000 workers and the welder average is based on 100's of workers. Based on this information, there is insufficient information to determine whether there is a significant trend in welder hearing loss incidence and the AF average incidence is relatively stable.

Figure 13: Percent of Permanent Threshold Shifts of AF Welders vs. AF Average.

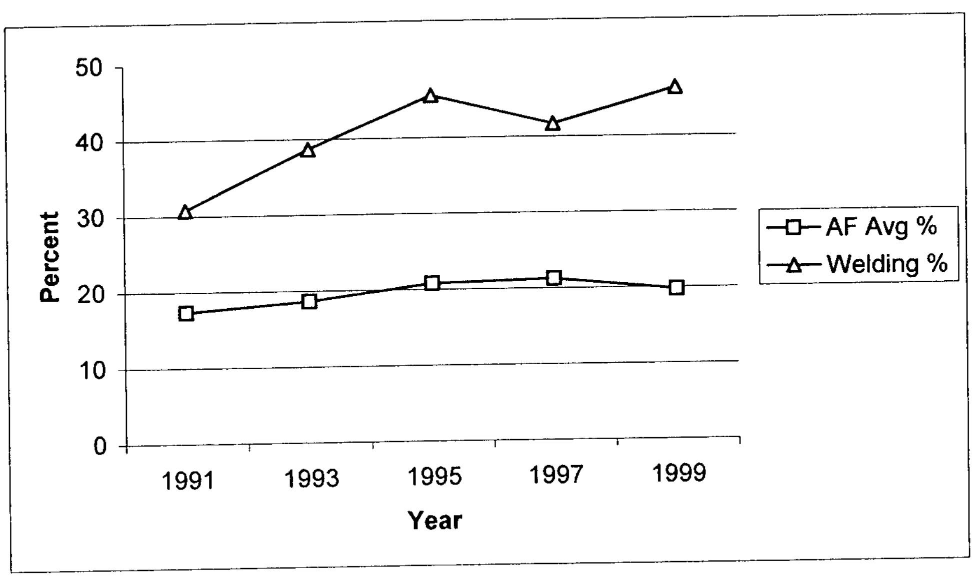


Table 28: Percent of Permanent Threshold Shifts of AF Welders vs. AF Average.

Table 28			
Year	AF Avg %	Welding %	# of Welders
1991	17	31	273
1993	19	39	181
1995	21	46	245
1997	21	42	120
1999	20	46	69

5.3.2 Average Welder Noise Exposures

The literature review section looked at a number of welder exposure studies. These studies varied in their approaches but consistently listed noise exposures exceeding 90 dBA as an eight hour Time Weighted Average (TWA). An Air Force study found 6 welders had a TWA of 91 dBA.[21] A Finnish study had a TWA of 92 dBA from 57 measurements.[22] A fabrication shop study found welders had an average TWA of 93 dBA from 14 measurements.[26] These studies indicate typical welder exposures are probably in the 90 to 95 dBA range.

5.3.3 Predicted hearing loss based on ANSI Model

Hearing loss can be predicted through the ANSI model. Tables 9 and 10 listed some typical values for Noise Induced Permanent Threshold Shifts (NIPTS) and Age-related Hearing levels (HTLA). These levels were given for the most sensitive individuals (10%), average (50%) and least sensitive individuals (90%). Based on the noise exposure levels for welders from the previous studies, 90 to 95 dBA seems a reasonable range of typical welder noise exposures. Choosing a hypothetical average worker who is a 40 year old male and has worked as a welder for 20 years, one can use the average (50%) levels for NIPTS and HTLA and produce Table 29 which predicts the overall average

hearing loss. The total amount of hearing loss for this worker would probably be 16 to 25 dB at 3000 Hz or 21 to 31 dB at 4000 Hz. Most of this hearing loss is from NIPTS.

Table 29: Predicted Average Hearing Loss for an Average 40-Year-Old Male with 20 Years of Exposure.[35]

Leq (dBA)	Freq (Hz)	Hearing Loss		
		NIPTS	HTLA	HTLAN
90	500	0	2	2
	1000	0	2	2
	2000	4	3	7
	3000	10	6	16
	4000	13	8	21
	6000	8	9	17
95	500	0	2	2
	1000	3	2	5
	2000	9	3	12
	3000	19	6	25
	4000	23	8	31
	6000	16	9	25

The hearing loss in Table 29 assumes the worker has not used hearing protection. If the typical welder is not wearing hearing protection and is exposed to 90 to 95 dBA, a high incidence of hearing loss would be expected from these predicted levels.

5.3.4 Summary of Hearing Loss Results

AF welders appear to have a hearing loss incidence double the AF average. The higher incidence rate has been present for several years. The incidence data are uncorrected data that can be affected by variables such as age, sex, race and exposure level. Typical welder noise exposure TWAs are in the 90 to 95 dBA range. This level of exposure would be expected to cause high incidence rates in unprotected workers over years of exposure.

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.0 Summary and Conclusions

The hypothesis stated that Air Force welders are losing their hearing because the total energy of exposure due to impulsive noise that occurs during welding operations is not being adequately characterized using existing equipment and protocols. The hypothesis has been disproved

The hypothesis was broken down into two objectives for evaluating welding operations: The first objective was that noise measurement equipment would be evaluated to assess radiofrequency interferences with measurement of exposure during welding operations. For this objective, some EMF interference is present, but it did not have an appreciable effect on measurements.

In practical terms, field industrial hygiene measurements for welding noise should always assess whether EMF interference is affecting measurements. This study showed an inactivated calibrator to be effective for these evaluations. A calibrator should be available with all sound level meters making this evaluation readily available.

The second objective was that noise measurement sampling rates and averaging times would be assessed to determine if there are differences in the amount of total energy being characterized during routine exposure assessments. For this objective, increasing sampling rate did not increase the amount of energy collected and hence the dose did not increase.

The data collected can be definitively used to quantitatively disprove the hypothesis based on the analyses of the sampling runs. This analysis and proof of the invalidity of the hypothesis will be a significant contribution to the current literature in this field. The results of this analysis indicate the need for additional research to explain the hearing loss of AF welders. Other explanations include: ototoxins, non-occupational exposure, other noise sources, inadequate use of hearing protection or data anomalies in the audiograms.

6.1 Future Research Directions

Since the hypothesis was disproved in this study, future research is needed to explain the hearing loss of AF welders. The first area to explore is use of hearing protection. Welders may not be wearing hearing protection while welding. One study of construction workers, which included welders, listed an average use rate of 15% for hearing protection.[33] There may be a perception that hearing protection is not needed while welding, since available lists of health hazards while welding list noise third behind welding fumes and ultraviolet light for health risks.[3] Some of the lists do not even include noise as a health risk from welding. A Finnish study noted 63% of the reported occupational diseases in welding shops were from occupational hearing loss.[28] The

ANSI model shows that typical levels of welding noise exposure may cause considerable NIPTS if hearing protection is not worn.

Another area for future research may be other noise sources in welding shops separate from the welding processes. Other noise sources in a welding shop would include grinding, hammering, chipping slag and other metal operations. Current noise exposure studies of welding shops conducted with noise dosimeters should incorporate these other sources into the overall TWA for each worker. Since these noise sources would already be included in current exposure measurements, this avenue is an unlikely explanation for the increased hearing loss incidence.

There may be data anomalies in the audiometric data used create the AF welder hearing loss incidence rates. This explanation could not be investigated as part of this study because individual audiometric data was unavailable. Also if there are significant differences in the welder population vs. AF population in terms of age, sex or race, it may have skewed the incidence rates.

Non-occupational noise exposure can be a major confounder in looking at hearing loss between occupational groups. There was no information available on these groups' non-occupational noise exposures. Non-occupational exposures of concern include hunting, racing and loud music. There is no reason to believe that welders had significantly different non-occupational exposure than other groups of AF workers.

The last future research area is ototoxins. Exposure to certain chemicals may cause hearing loss. These chemicals are called ototoxins. Ototoxins may cause hearing loss alone or in conjunction with noise exposure. ACGIH recommends audiometric monitoring for personnel who are exposed to 20% of the TLV for ototoxins. Some ototoxins may act synergistically with noise exposure to cause hearing loss. Known ototoxins to which welders are exposed include solvents, heavy metals and carbon monoxide.[11] Research in the area of ototoxins is in the mechanistic stage and is not at the field industrial hygiene level yet.

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LIST OF ABBREVIATIONS

AAC	Air Carbon Arc Cutting
AC	Alternating Current
ACGIH	American Conference of Governmental Industrial Hygienists
A/D	Analog to Digital
AF	Air Force
AFB	Air Force Base
AIHA	American Industrial Hygiene Association
AL	Aluminum
ANSI	American National Standards Institute
AWS	American Welding Society
B&K	Bruel and Kjaer
DAT	Digital Audiotape
dB	Decibels
dBA	Decibels A- Weighted
dBC	Decibels C- Weighted
dBF	Decibels Flat-weighted
DC	Direct Current
EEH	Equal Energy Hypothesis
EMF	Electromagnetic Field
GMAW	Gas Metal Arc Welding
GTAW	Gas Tungsten Arc Welding
HCP	Hearing Conservation Program
HTLA	Age-Related Hearing Levels
HTLAN	Total Hearing Threshold Level Associated with Age and Noise
Hz	Hertz
ISO	International Organization for Standardization
kHz	Kilohertz
Leq	Equivalent Sound Level
MHz	Megahertz
NIOSH	National Institute of Occupational Safety and Health
NIPTS	Predicted Noise Induced Permanent Threshold Shift
PAC	Plasma Arc Cutting
OFC	Oxy-Fuel Cutting
OEL	Occupational Exposure Limit
OSHA	Occupational Safety and Health Administration
RMS	Root Mean Square
RTA	Real Time Analyzer
SMAW	Shielded Metal Arc Welding
SPL	Sound Pressure Level
ST	Steel
TLV	Threshold Limit Value
TWA	Time Weighted Average
USAF	United States Air Force